# EXPERIMENTAL AND FINITE ELEMENT EVALUATION OF BENDING FOR MILD STEEL

AHMAD AIMAN BIN RAMLAN

Report submitted in partial fulfilment of the requirements
for the award of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

## ABSTRACT

Finite element evaluation is one of the methods in predicting the springback angle in sheet metal bending. Predicting the springback is important since to produce the accuracy part geometry, the design of the die and bending tool must be accurate. This thesis aims to evaluate the reliability of finite element method by comparing the results with experimental results. The effect of parameters such as anisotropy in springback also has been studied. Abaqus software has been used to simulate the bending process and the mechanical properties provided from tensile test will be used to run the simulation. In the U-bending experiment, the die were clamped on stamping machine and the Mild Steel sheets then have been bent before the springback being measured with SolidWorks software. The results from the experiment and simulation is slightly different for the springback angle $\Theta_1$ , which the simulation shows increasing the orientation will increase the springback, and for the experimental, the springback higher at 0 degree orientation angle, and lower at 45 degree. For the springback angle $\Theta_2$ , the simulation and experimental result show that increasing the orientation angle will increase the amount of springback. Finite element method can be used to predict the springback since the pattern of the graphs are nearly the same and percentages of error are below 10 %. It can be comprehended that the finite element method are suitable method to predict the springback angle of sheet metal bending. The further study on parameters that effected bending process will make the finite element method is important in the future.

## ABSTRAK

Kaedah analisis simulasi merupakan salah satu kaedah untuk meramal pembentukan bangkit kembali dalam pembengkokan kepingan logam. Ramalan bangkit kembali amat penting kerana untuk menghasilkan produk yang tepat, reka bentuk alat acuan dan peralatan pembengkokan mestilah tepat. Laporan ini bertujuan untuk menilai kebolehan kaedah simulasi dengan membandingkan keputusan simulasi dengan keputusan eksperimen. Kesan parameter seperti anisotropi dalam bangkit kembali juga dikaji. Perisian Abaqus telah digunakan untuk mensimulasikan proses lenturan dan sifat-sifat mekanik yang disediakan dalam ujian regangan akan digunakan untuk menjalankan simulasi. Dalam eksperimen lenturan-U, alat acuan telah dikapit pada mesin tekanan dan kepingan " Mild Steel " kemudian dibengkokan sebelum nilai bangkit kembali diukur dengan perisian Solidworks. Hasil daripada eksperimen dan simulasi adalah sedikit berbeza untuk sudut bangkit kembali, $\Theta_1$ yang mana simulasi menunjukkan peningkatan sudut orientasi akan meningkatkan bangkit kembali dan untuk eksperimen, bangkit kembali lebih tinggi pada sudut orientatasi 0 darjah dan lebih rendah pada 45 darjah. Bagi sudut bangkit kembali $\Theta_2$ , simulasi dan hasil eksperimen menunjukkan bahawa peningkatan sudut orientasi akan meningkatkan jumlah bangkit kembali. Kaedah simulasi boleh digunakan untuk meramal bangkit kembali kerana corak graf adalah hampir sama dan peratusan ralat di bawah 10 % . Dapat difahami bahawa kaedah simulasi sesuai untuk meramal sudut bangkit kembali bagi pembengkokan kepingan logam. Kajian lanjut mengenai parameter yang mempengaruhi proses pembengkokan adalah penting pada masa akan datang.

# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# LIST OF SYMBOLS

| | |
|---|---|
| $\sigma^2$ | Variance |
| Fmax | Bending Force |
| $\mu$ | Mean |
| $\Delta\theta/\theta$ | Spring back ratio |
| $n$ | Strain hardening exponent |
| $R$ | Normal anisotropic value |
| $v$ | Poisson's ratio |
| $E$ | Young's modulus |
| $t$ | Sheet thickness |
| $\rho$ | Neutral axis |
| $\Delta\theta$ | Spring back angle |
| $I$ | Inertia moment of cross-section per unit width |
| $M(\alpha)$ | Bending moment along the bending surface |
| $R_n$ | Neutral layer radius of the sheet |
| $K$ | Ultimate tensile strength |
| $w$ | Die gap |
| $t$ | Sheet thickness |
| $\Delta K$ | Spring back curvature |
| $M$ | Bending moment |
| $L$ | Inertia moment of cross-section |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AISI | American Iron and Steel Institute |
| ASTM | American Society for Testing and Material |
| TRIP | Transformation Induced Plasticity |
| CNC | Computer Numerical Control |
| UTS | Ultimate Tensile Strength |
| DKL | Daw-Kwei Leu |
| DFPH | Dongye Fei and Peter Hodgson |
| FEA | Finite Element Analysis |
| CRES | Called-Corrosion-Resistant |

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

This chapter provides a brief overview of the entire project consists of project background, problem statement, objectives, scopes of the works and organization of the thesis.

## 1.2 PROJECT BACKGROUND

Bending of sheet metal is one of the widely used processes in manufacturing industries especially in the automobile and aircraft industries. This bending operation is commonly used because the process is simple and final sheet product of desired shape and appearance can be quickly and easily produced with relatively simple tool set. In bending operation, plastic deformation is followed by some elastic recovery when the load is removed due to the finite modulus of elasticity in materials. During the loading and unloading process, elastic strain is released and the residual stresses redistribute through the sheet thickness producing spring-back. Basically, this project deals with experimental and finite element evaluation of bending for mild steel. In this project, bending analysis will take springback as one of the part of bending analysis.

Through this project, bending analysis can be made in term of knowing about spring-back of mild steel material. Many factors affect springback such as types of material, types of bending, and thickness of material and sheet anisotropy.

## 1.3 PROBLEM STATEMENT

Metal bending is the most common operation to change the shape of material by plastically deforming. Although this process is simple but it has a major problem which is spring-back. Springback can be described as the additional deformation of sheet metal parts after the loading is removed, which can lead to production of unacceptable products with wrinkle, tear, poor dimension precision, and so on.

In the past, sheet metal bending processes are dependent on the designer’s experience and involve trials and errors to obtain the desired result, so the study of springback or amount of spring-back that influenced by various factors are really important.

## 1.4 OBJECTIVES

1. To determine springback angle in sheet metal bending for Mild Steel.
2. To determine the influence of anisotropy,R on springback.
3. To determine reliability of Finite Element Method (FEA) in sheet metal by comparing with the experimental results.

## 1.5 SCOPE OF WORKS

1. To study the basic understanding of spring-back behaviour from the past researchers (Literature Review).
2. To conduct experiments of tensile test to determine mechanical properties of Mild steel.
3. To perform Finite Element Evaluation analysis of bending for Mild steel.
4. To conduct experiment of sheet metal bending.
5. To analyse and compare the simulation and experimental result.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter will discuss about theory of bending, types of bending, materials and parameters involved that causing the bending. This chapter will have all necessary information from journal, book and articles that are related to this project and also about the spring back study. The sources for the literature review are library books, journal from established databases such as Science Direct and Scopus, article and also newspaper article.

## 2.2 SHEET METAL FORMING

Sheet metal forming processes are those in which force is applied to a piece of sheet metal to modify its geometry rather than remove any material. The applied force stresses the metal beyond its yield strength, causing the material to plastically deform, but not to fail. By doing so, the sheet can be bent or stretched into a variety of complex shapes. There are a few examples of  common sheet metal forming such as blanking and piercing, bending, stretching, stamping or draw die forming, Coining and ironing and many more (Marciniak, 2002.)

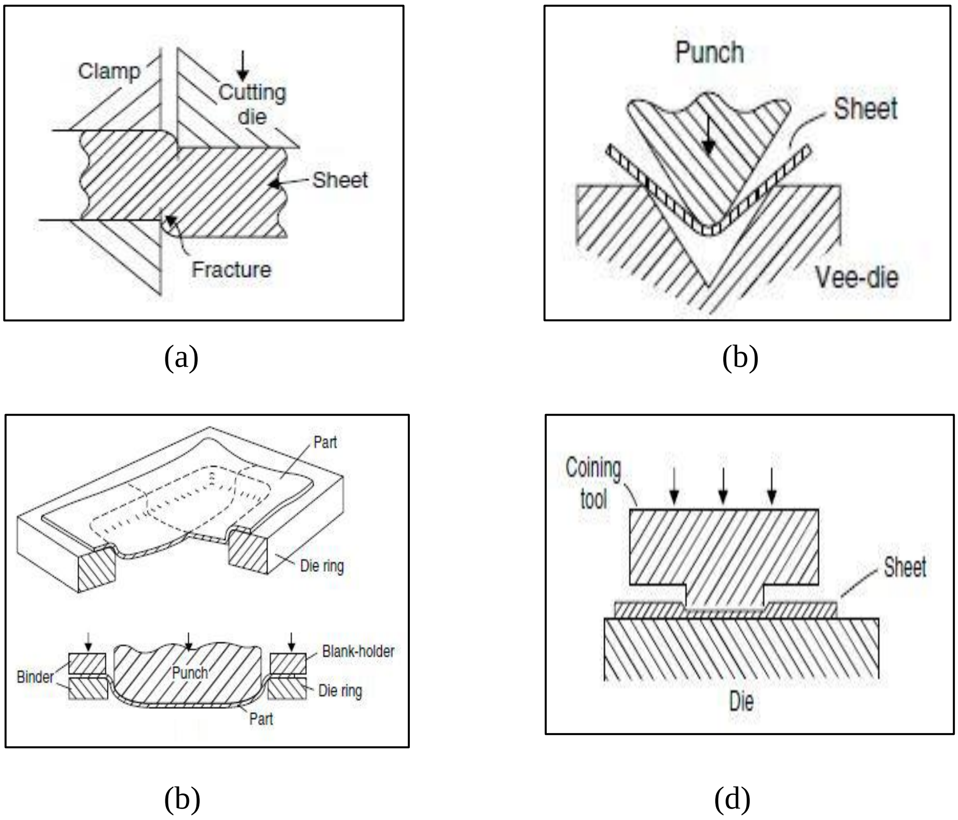



**Figure 2.1 :** (a) Basic cutting process of blanking an piercing. (b) Example of sheet metal bending process. (c) Typical part formed in a stamping or draw die. (d) Thinning a sheet locally using a coining tool.

Source : (Marciniak, Duncan,Hu, 2002)

In sheet metal forming industry, especially in sheet bending process, spring-back has a very significant role. In this process, the dimension precision is a major concern, due to the considerable elastic recovery during unloading which leads to spring-back. Also, under certain conditions, it is possible for the final bend angle to be smaller than the original angle. Such bend angle is referred to as spring-go or spring-forward. The amount of spring-back/ spring-go is influenced by various process parameters, such as tool shape and dimension, contact friction condition, material properties, sheet anisotropy, and sheet thickness.

### 2.2.1 Material Properties that affect Sheet Metal Formability

a) **Ductility:** Metal used in the sheet metal work must be ductile. If we use a brittle metal it can easily undergo failure during forming. That's why metal's ductility is very important in sheet metal working.

b) **Yield strength**: Yield strength of a material used in sheet metal forming must be low. High strength metals have reduced stretch distribution characteristic, making them less stretchable and drawable than lower strength metals. Stretch distribution characteristic determines the steel's ability to distribute stretch over a large surface area.

c) **Elastic modulus**: Stretch distribution affects not only stretch ability, but also elastic recovery , or spring back, and the metal's total elongation.

d) **Discontinuously Yielding**: Low carbon show a discontinuous yielding accompanied with the formation of Lǖder bands, which reduces the surface quality of the end product. In order to remove the discontinuous yield point a temper rolling (rolling where a few percent of reduction is applied) can be applied.

e) **Work Hardening Rate (n)**: Work hardening rate is a very important sheet metal forming parameters. When increases material's resistance to necking also increase. The work hardening is the mechanism, which prevents local yielding and increase the uniform elongation.

f) **Anisotropy (Directionality):** Anisotropy is another factor that affect formability. Once consequence of directionality is a change in mechanical properties with direction. When forming sheet metal, practical consequences of directionality include such phenomena as excess wrinkling, puckering, ear-formation, local thinning, or actual rupture.

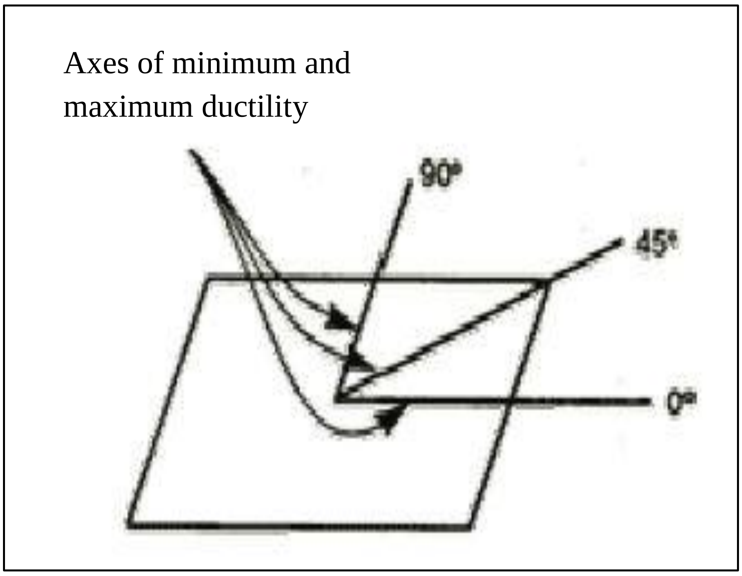



**Figure 2.2**: Directionality in properties of a Rolled Sheet.
Source: (Chan et al., 2004)

## 2.3 THEORY OF SHEET METAL BENDING

Bending can be defined as shaping materials without removing any chips around a definite axis through or without heat. Bending is the process of placing a sheet of metal over the matrix on the press bed where the sheet is bent around the tip of the punch as it enters the die. Bending dies are the setup, proper to the required piece shape, consisting of a female die and punch, and making permanent changes on steel sheet material (Tekaslan.O.V, 2007).

(a) (b)

**Figure 2.3 :** Pictures of V-die bending: a) under load and (b) after unloading.
Source: (Kardes Sever et al., 2011)

Bending along a straight line is the most common of all sheet forming processes as shown in Figure 2.3, it can be done in various ways such as forming along the complete bend in a die, or by wiping, folding or flanging in special machines, or sliding the sheet over a radius in a die. A very large amount of sheet is roll formed where it is bent progressively under shaped rolls. Failure by splitting during a bending process is usually limited to high-strength, less ductile sheet and a more common cause of unsatisfactory bending is lack of dimensional control in terms of springback and thinning. A few among the most common applications of sheet metal parts are as automobile and aircraft panels, housings, cabinets etc. Customization of sheet metal parts to produce parts of varying configurations and sizes is a very common occurrence in a sheet metal fabrication scenario (Diegel, 2002).

.

## 2.4 TYPES OF BENDING

There are several types of bending that commonly used in the industries such as Air bending, Bottoming, Coining, V- bending, and U-bending. A bending tool must be decided depending on the shape and severity of bend (Boljanovic, 2004).

### 2.4.1 Air Bending

Air bending is a bending process in which the punch touches the work piece and the work piece does not bottom in the lower cavity. As the definition of springback, when the punch is released, the work piece springs back a little and ends up with less bend than that on the punch (greater included angle).There is no need to change any equipment or dies to get different bending angles since the bend angles are determined by the punch stroke.

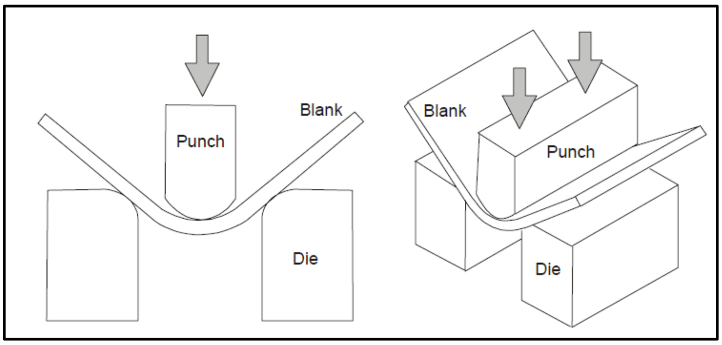



**Figure 2.4 :** Air bending process

Source : ( Diegel, 2002)

### 2.4.2 Bottoming

Bottoming is a bending process where the punch and the work piece bottom on the die. In bottom bending, spring back is reduced by setting the final position of the punch such as that the clearance between the punch and die surface is less than the blank thickness, the material yields slightly and reduces the spring back.

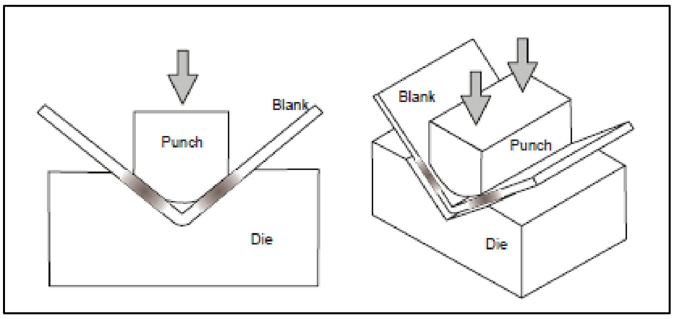



**Figure 2.5 :** Bottoming process.

Source : (Diegel, 2002)

### 2.4.3 Coining

Bending process in which the punch and the work piece bottom on the die and compressive stress is applied to the bending region to increase the amount of plastic deformation also can be called as coining

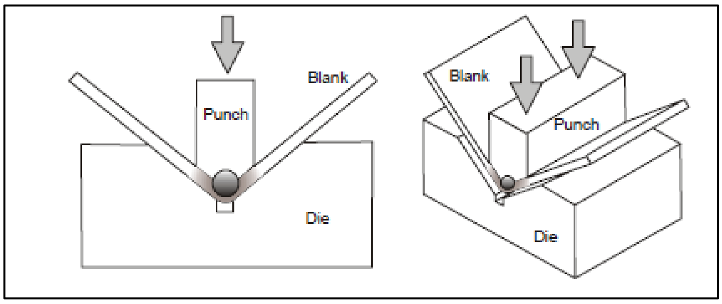



**Figure 2.6:** Coining process.

Source : (Diegel, 2002)

### 2.4.4 V-bending

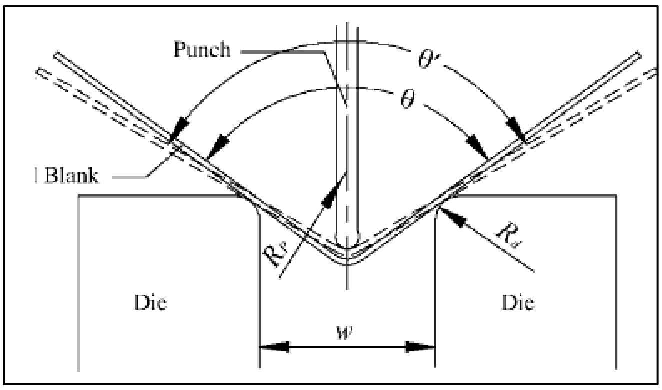


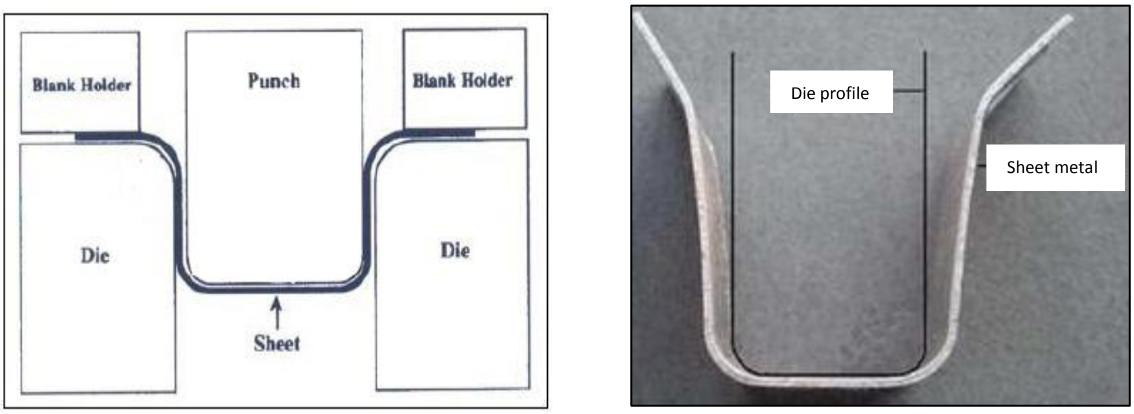

**Figure 2.7 :** Illustration of V-die bending.

Source : ( Esat et al.,2002)

The V-die bending process is the bending of a V-shaped part in a single die. The work piece is bent between a V-shaped punch and die. The force acting on the punch causes punch displacement and then the workpiece is bent. The work piece is initially bent as an elastic deformation. With continued downward motion by the punch, plastic deformation sets in when the stresses exceed the elastic limit. This plastic deformation starts on the outer and inner surfaces directly underneath the punch.

### 2.4.5 U- bending

U – bending is performed when two parallel bending axes are produced in the same operation. A backing pad is used to forces the sheet contacting with the punch bottom (Marciniak , 2002). Generally U – bending process can be divided into two steps, loading and unloading. In the loading step, the punch will completely moves down and the metal is being bent into the die. During this step, the work piece undergoes elastoplastic deformation and temperature increase under frictional resistance. For the second step which is unloading step, the deformed sheet metal is ejected from the tool set and metal was experiencing the residual stress release and the temperature drop to reach a thermo-mechanical equilibrium state (Cho,2003) .




(a) (b)

**Figure 2.8 :** Sheet metal U-bending: (a) Schematic diagram of U – bending process (b) Deformed specimen after unloading.

Source : (Bakhshi-Jooybari et al.,2009)

U-bending process is often used to manufacture sheet parts like channels, beams and frames. In this process, the sheet metal usually undergoes complex deformation history such as stretch–bending, stretch–unbending and reverse bending. When the tools are removed, in addition to springback, sidewall curl often happens, which makes the prediction of springback become more difficult.

Different methods, such as analytical method, semi-analytical method and finite element method (FEM), have been applied to predict the sheet springback of U-bending. Xu (2005) and Samuel (2000), applied FEM to simulate the forming and springback process of sheet U-bending and reviewed the effects of numerical parameters, tools geometry and process parameters on the predicted accuracy of springback. However, FEM is a time-consuming method and also is very sensitive to numerical parameters such as element type and size, algorithms, contact definition and convergence criterion for solution etc . (Zhang, 2007)

## 2.5 PARAMETERS INVOLVED IN U- BENDING

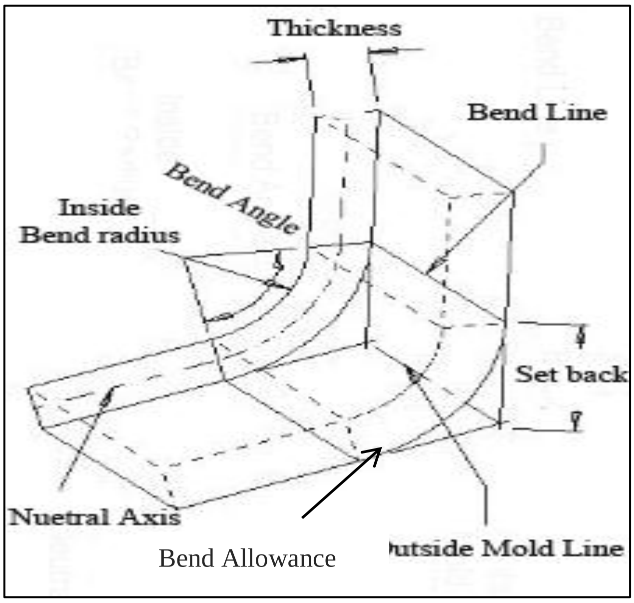



**Figure 2.9 :** Parameters of U- bending.

Source : (Boljanovic, 2004)

1. **Bend Allowance** – The length of the arc through the bend area at the neutral axis.
2. **Bend Angle** – The included angle of the arc formed by the bending operation.
3. **Bend Compensation** – The amount by which the material is stretched or compressed by the bending operation. All stretch or compression is assumed to occur in the bend area.
4. **Bend Lines** – The straight lines on the inside and outside surfaces of the material where the flange boundary meets the bend area.
5. **Inside Bend Radius** – The radius of the arc on the inside surface of the bend area.
6. **K-factor** – Defines the location of the neutral axis. It is measured as the distance from the inside of the material to the neutral axis divided by the material thickness.

7. **Mold Lines** – For bends of less than 180 degrees, the mold lines are the straight lines where the surfaces of the flange bounding the bend area intersect. This occurs on both the inside and outside surfaces of the bend.
8. **Neutral Axis** – Looking at the cross section of the bend, the neutral axis is the theoretical location at which the material is neither compressed nor stretched.
9. **Set Back -** For bends of less than 180 degrees, the set back is the distance from the bend lines to the mold line. (Boljanovic, 2004).

## 2.6 SPRING BACK IN U – BENDING

Spring back generally defined as additional deformation of sheet metal parts after the loading is removed (Zhang, 2007). Spring back is a major problem in sheet metal bending technique. Several bending operations done on sheet metal are air bending, V-die bending, rubber die bending and U-bending. In U-bending, the material may exhibit negative and positive spring-back caused by deformation as the punch completes the bending operation(fem of v-bending). The amount of spring-back/ spring-go is influenced by various process parameters, such as tool shape and dimension, contact friction condition, material properties, sheet anisotropy, and sheet thickness (Bakshi,2006).

There are several researchers that have investigated and attempted to obtain a basic understanding of spring back behaviour. The effect of bending angle on spring back of six types of materials with different thicknesses in V-die bending has been studied by Tekiner et al (2001) experimentally showed the effect of combined hot die and cold punch on reduction of spring-back of aluminium sheets. Li et al. (2005) also showed that the accuracy of spring-back simulation is directly affected by the material hardening model.